The Impacts of Vegetation on Summer Extreme Temperature of 4 Major Cities in China Based on Scatter Analysis and Linear Trend Analysis

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Abstract. In the summer of 2022, the extreme high temperature phenomenon is particularly obvious in China, especially in Chongqing, Zhengzhou, Guangzhou, and Shanghai. Some studies have pointed out that there is a strong correlation between vegetation activity and regional climate change, and some vegetation types can mitigate the rise of extreme temperature. However, few papers can put forward inductive suggestions on what types of vegetation can effectively alleviate the extreme temperature in China. Therefore, in this paper the extreme temperature data of CMIP6 (tasmax) is used to explore the correlation between the vegetation cover rate and the extreme temperature of the four major cities in China through the scatter analysis and linear trend analysis. It is found that the vegetation cover rate has a significant correlation ($p<0.05$) with the extreme temperature: The high vegetation cover rate has a negative correlation with the extreme temperature ($p=0.01$), and the low vegetation cover rate has a positive correlation with the extreme temperature ($p=5.86 \times 10^{-9}$). According to the geographical location, 4 cities are divided into two types: inland cities and coastal cities. The results show that: (1) planting high vegetation may be more conducive to the mitigation of extreme temperature; (2) the increase of low vegetation coverage may be more conducive to the reduction of temperature rise rate; (3) inland cities may need to plant more high vegetation than coastal cities to mitigate extreme temperature.

Keywords: Extreme temperature, scatter analysis, linear trend, vegetation cover rate.

1. Introduction

In recent years, extreme weather has occurred frequently under the background of global warming, causing great economic losses to many countries. In the summer of 2022, the extreme high temperature phenomenon in China is particularly obvious, especially in Chongqing, Zhengzhou, Guangzhou and Shanghai. How to adjust the climate to mitigate the destructive effects of extreme climate is an urgent problem to be solved. It is worth noting that the underlying surface, the boundary surface of the lower atmosphere movement, is an important source of heat and water vapor in the atmosphere and an important factor restricting the formation and change of climate [1]. Vegetation can change the reflectivity and thermal characteristics of the underlying surface, which is one of the factors affecting climate change [2].

There is a certain relationship between vegetation and temperature, which is recognized by scholars [3,4].As for the regulation of vegetation on extreme temperature, many scholars have made relevant studies. Yang et al. pointed out that the vegetation coverage has a negative correlation with the high temperature in urban areas, and the existence of vegetation can have an obvious cooling effect on the high temperature in summer [5-7].

Some scholars also pointed out that in some cases, vegetation can not only regulate the climate, but also be affected by extreme weather: for example, extreme events will reduce vegetation productivity [8-10]. Other scholars have found that although vegetation can play a certain role in regulating climate, its regulation effect is lagging behind [11]. In order to find a way of planting vegetation to alleviate extreme temperature, it is necessary to explore a vegetation planting plan suitable for China.

Before that, some scholars have given some suggestions on urban vegetation planting according to the relationship between vegetation and temperature [12].However, few papers can put forward inductive suggestions on what type of vegetation can effectively alleviate extreme temperature in China [13]. Some conclusions are too general to be implemented, and some conclusions are too limited to small areas.

In this paper, 4 cities with frequent extreme high temperature in 2022: Chongqing, Zhengzhou, Guangzhou and Shanghai are selected as representative research areas. Using the average vegetation coverage data of ECMWF in 2022, the vegetation is divided into two types: high and low vegetation. The scattered point and linear trend analysis are carried out with the tasmax data of summer 2022 (JJA) averaged by 14 CMIP6 models, and the correlation coefficient analysis between tasmax and vegetation is carried out. Cities are also subdivided into inland and coastal cities to analyze the impact of different vegetation coverage in different geographical locations (coastal and inland) on extreme climate. Finally, the three problems of (1) what vegetation type can mitigate the extreme temperature rise (2) what vegetation type can mitigate the extreme temperature rise rate better (3) how to adopt specific vegetation planting plans in coastal and inland cities to mitigate the extreme temperature will be solved.

2. Data Introduction and Research Areas

2.1. Data Introduction

2.1.1 Data sources

All data used in this study are public. The web address for obtaining the required data, the data variable names and file suffix names used in this article are shown in Table 1. CMIP6 is used to obtain temperature data (tasmax means the maximum of surface air temperature) and ECMWF is used to obtain vegetation data. Shapefiles is used to crop NetCDF files to specific areas.

Table 1. Sources of data sets used in the study

Number	Datasets	URL	Variables	Suffix
1	CMIP6	https://esgf-node.llnl.gov/search/cmip6/	tasmax	.nc
2	ECMWF	https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels-monthly-means?tab=form	cvh,cvl	.nc
3	Shapefiles	http://datav.aliyun.com/portal/school/atlas/area_selector	\	.shp

2.1.2 Data processing

CMIP6 has many models to choose from. This paper refers to some literatures to select the model more suitable for China's region [14,15]. Finally, 14 air temperature (tasmax) data were screened out. The conditions for filtering these data are shown in Table 2.

Table 2. Description of the selected 14 tasmax data attributes

Number	Source ID	Nominal Resolution	Experiment ID	Variant Label
1	ACCESS-CM2	250 km	ssp585	r1i1p1f1
2	ACCESS-ESM1-5	250 km	ssp585	r1i1p1f1
3	BCC-CSM2-MR	100 km	ssp585	r1i1p1f1
4	CAS-ESM2-0	100 km	ssp585	r1i1p1f1
5	CMCC-ESM2	100 km	ssp585	r1i1p1f1
6	EC-Earth3	100 km	ssp585	r1i1p1f1
7	EC-Earth3-CC	100 km	ssp585	r1i1p1f1
8	EC-Earth3-Veg	100 km	ssp585	r1i1p1f1
9	EC-Earth3-Veg-LR	100 km	ssp585	r1i1p1f1
10	FGOALS-g3	250 km	ssp585	r1i1p1f1
11	FIO-ESM-2-0	100 km	ssp585	r1i1p1f1
12	GFDL-ESM4	100 km	ssp585	r1i1p1f1
13	IPSL-CM6A-LR	250 km	ssp585	r1i1p1f1
14	NESM3	250 km	ssp585	r1i1p1f1

In this paper, NCO (NetCDF operator) is used to extract a specific time from the downloaded NC file to calculate the average temperature in summer 2022 (JJA), and the grid size is adjusted by bilinear interpolation method to achieve the fusion of different resolution data. After averaging 14 temperature data, the tasmax data required for this study is obtained.

As for the vegetation data, the average vegetation coverage in 2022 is adopted in this paper because the vegetation coverage data does not change much. Vegetation is divided into two types, as low vegetation and high vegetation [16]. High vegetation consists of evergreen trees, deciduous trees, mixed forest or woodland, and interrupted forest. Low vegetation consists of crops and mixed farming, irrigated crops, short grass, tall grass, tundra, semidesert, bogs and marshes, evergreen shrubs, deciduous shrubs, and water and land mixtures. In the ECMWF dataset, the variable “cvh” represents “high vegetation coverage” and the variable “cvl” represents “low vegetation coverage”.

2.2. Research Areas

The geographical locations of the four cities are shown in Fig.1. Among them, Chongqing and Zhengzhou are inland cities, and Guangzhou and Shanghai are coastal cities. The following map is made by importing the shapefiles obtained from the website in Table 1 through ArcGIS software.

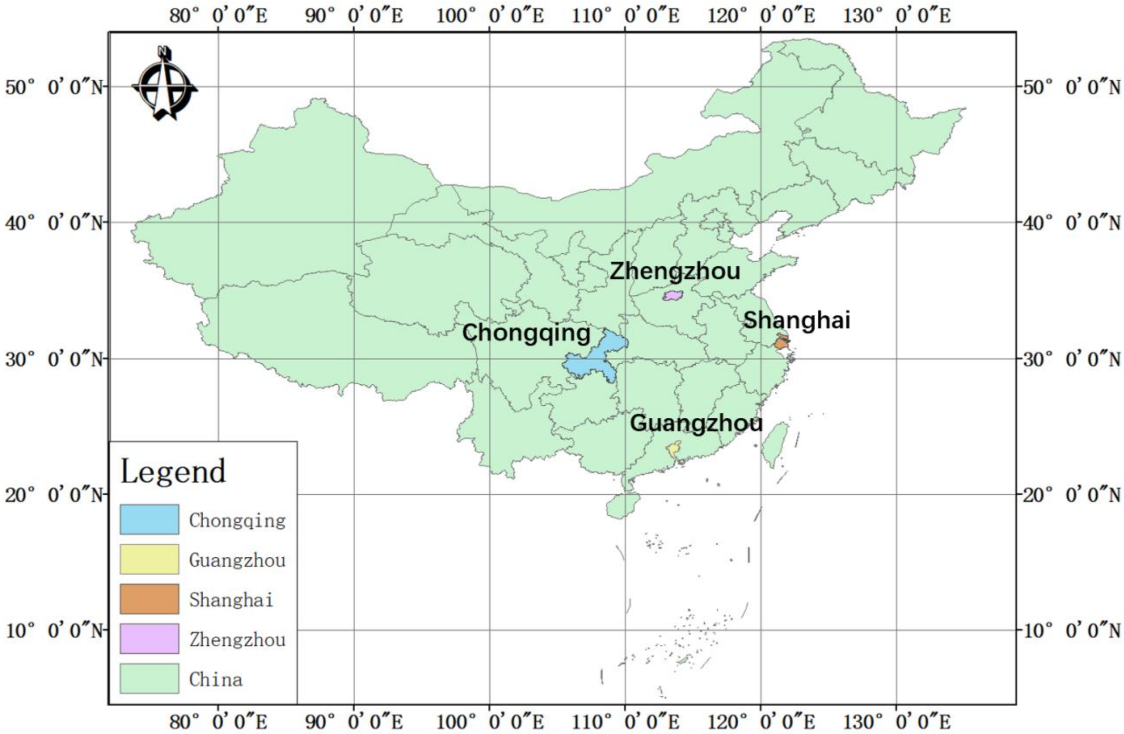

Fig. 1 Geographical location of the 4 research areas

3. Correlation Between tasmax and Vegetation Coverage in 4 cities

3.1. Regional Analysis

In order to clearly see the relationship between vegetation and high temperature, this paper averages the temperature in different regions according to the scope of urban zoning, and displays the regional temperature on the map in colors. The regional vegetation coverage is represented by the stacked column chart on the map.

The maps in Fig.2 represent the distribution of tasmax data in four regions, and the stacked plots on the maps represent the proportion of high (in green) and low vegetation (in yellow) coverage. It can be seen from the figure that the higher the high vegetation coverage (cvh) in a certain area, the less likely the high temperature will occur, which also verifies the role of the vegetation mentioned above [5-7] in regulating the temperature.

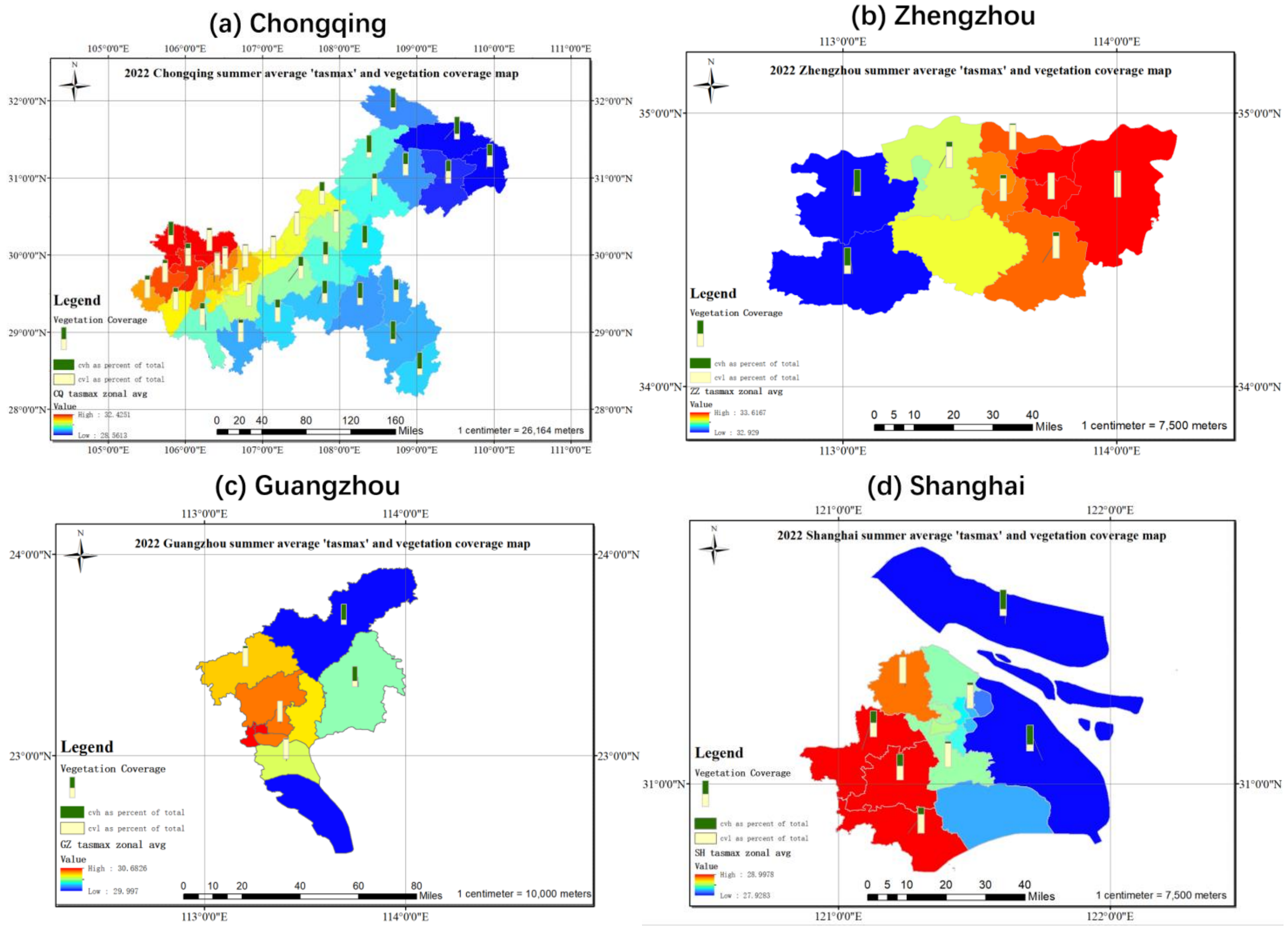

Fig. 2 2022 summer average tasmax and vegetation coverage maps

It can be seen from the Fig.2 that the vegetation coverage data missed in some areas because of low resolution. In order to maintain the accuracy of the data and reflect the distribution of regional vegetation coverage most truly, this paper does not interpolate the vegetation data to avoid errors caused by data distortion [17].

3.2. Correalation Analysis

3.2.1 Correlation between tasmax and vegetation coverage

In order to deeply study the relationship between high and low vegetation coverage and tasmax, the linear trend between vegetation cover rate and tasmax need to be explored.

Fig.3 is a scatter diagram obtained by randomly selecting the points in four study areas. Table 3 is the data description of the sample points selected for scatter analysis. It can be seen from Fig.3 that cvh (high vegetation cover rate) is negatively correlated with tasmax, and cvl (low vegetation cover rate) is positively correlated with tasmax. Their p-value (Table 4.) are all less than 0.05, which indicates that the vegetation coverage is significantly correlated with tasmax.

From this, we can draw a conclusion that if the high vegetation coverage is increased, the extreme temperature may decrease; If the low vegetation coverage is too high, the extreme temperature may rise.

This conclusion is contrary to the widely believed conclusion, because it is generally believed that no matter what type of vegetation, all of them can play a role in regulating climate. This key conclusion is also the innovation of this paper.

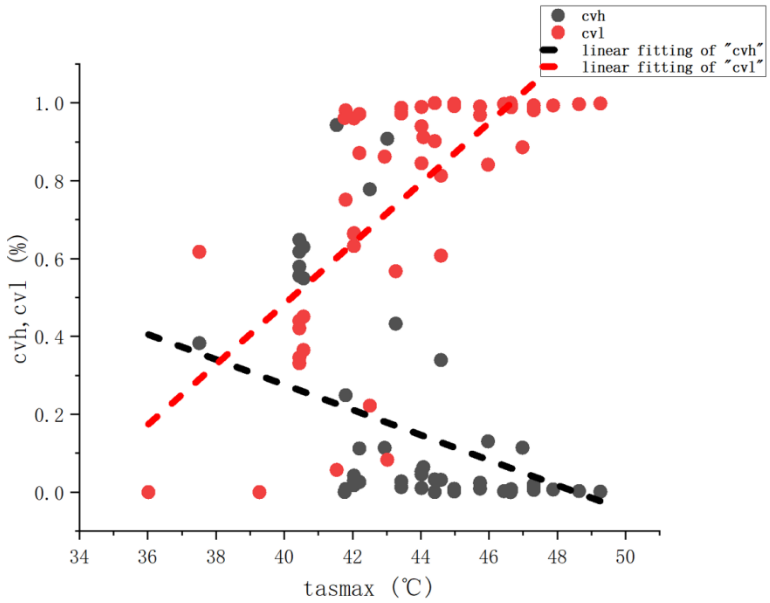

Fig. 3 Scatter analysis of cvh, cvl, and tasmax (2022) and their correlations in 4 cities

Table 3. Descriptive statistics of cvh, cvl and tasmax

Variable	Counts	Mean	SD	Sum	Min	Max
tasmax	51	43.31031	2.94443	2208.82595	36.01876	49.26061
cvh	51	0.16904	0.26793	8.62085	3.49262E-10	0.94322
cvl	51	0.74012	0.3223	37.74604	3.49262E-10	0.99979

Table 4. Pearson correlations of cvh, cvl and tasmax

		tasmax	cvh	cvl
tasmax	Pearson Corr.	1	-0.35502*	0.70885*
	p-value	--	0.01058	5.86436E-9
cvh	Pearson Corr.	-0.35502*	1	-0.67809*
	p-value	0.01058	--	4.58403E-8
cvl	Pearson Corr.	0.70885*	-0.67809*	1
	p-value	5.86436E-9	4.58403E-8	--

2-tailed test of significance is used
*: Correlation is significant at the 0.05 level

From the above analysis, planting more high vegetation may be more conducive to the mitigation of regional extreme temperature, while too much low vegetation may be detrimental to regional climate stability. This provides an idea for urban greening: protect high vegetation and increase the planting intensity of high vegetation.

3.2.2 Correlation between tasmax change rate and vegetation coverage

The relationship between extreme temperature change rate (“tcr”) and vegetation coverage was also studied. The extreme temperature change rate is obtained by calculating the average monthly change rate of tasmax in 2022 summer.

Fig.4 is a 3y-axis combination diagram describing the histogram of high and low vegetation coverage and the dotted line diagram of “tcr”.

It can be seen from Fig.4 that the higher the low vegetation coverage (in yellow), the lower the temperature rise rate (in blue) (since the average temperature change rate is positive, the positive “tcr” can also be regarded as the temperature rise rate). However, it is difficult to see the relationship between high vegetation coverage (in green) and temperature rise rate.

In order to strengthen the conclusion, this paper randomly extracts some “cvh” “cvl” and “tcr” data (see Table 5 for specific information) and calculates their correlation coefficients (see Table 6).The correlation coefficient in Table 6 can also prove this: there is a negative correlation between “cvl” and “tcr”, and there is a significant correlation between them ($p < 0.05$), while there is no significant correlation between “cvh” and “tcr”.

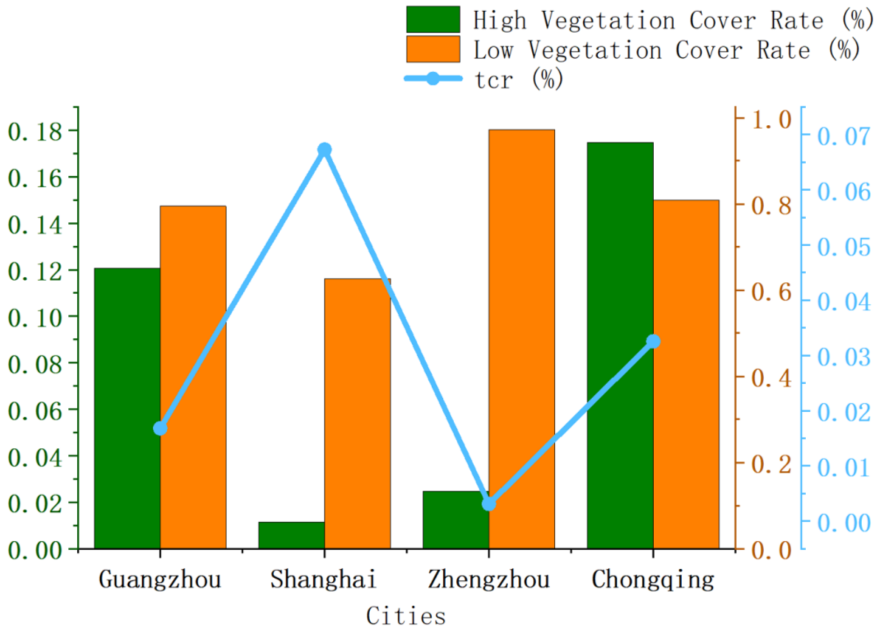

Fig. 4 3y-axis diagram and correlation analysis of “cvh” “cvl” and “tcr”

Table 5. Descriptive statistics of cvh, cvl and tasmax

Variable	Counts	Mean	SD	Sum	Min	Max
tcr	144	0.03105	0.01094	4.47096	-0.00282	0.07368
cvh	144	0.14416	0.18531	20.7584	1.22076E-4	0.90158
cvl	144	0.84034	0.19217	121.00922	0.09842	0.99808

Table 6. Pearson correlations of cvh, cvl and tasmax

		tcr	cvh	cvl
tcr	Pearson Corr.	1	0.0399	-0.2112*
	p-value	--	0.6349	0.01105
cvh	Pearson Corr.	0.0399	1	-0.94201*
	p-value	0.6349	--	3.26512E-69
cvl	Pearson Corr.	-0.2112*	-0.94201*	1
	p-value	0.01105	3.26512E-69	--

2-tailed test of significance is used
*: Correlation is significant at the 0.05 level

This also provides a new idea for adjusting the urban greening structure: increasing the planting of low vegetation is conducive to the reduction of the temperature rise rate. It is mentioned that planting a large number of low vegetation may not be conducive to the mitigation of extreme temperature, which indicates that the coverage of low vegetation needs to be controlled within a suitable range, not too high or too low.

4. Correlation Between tasmax and Vegetation Coverage in Inland and Coastal Cities

4.1. Inland Cities

It can be observed from the above fig. 4 that if the four research cities are divided into two groups, taking Guangzhou and Shanghai as coastal cities and Chongqing and Zhengzhou as inland cities, it can be found that the two groups of data have their own regularity and characteristics. In fact, the relationship between vegetation and temperature is indeed different depending on the type of city [18,19].

Fig.5 is the scatter analysis of tasmax and vegetation coverage of inland cities represented by Chongqing and Zhengzhou. Table 7 is the data description of the sample points selected for scatter analysis and Table 8 is the analysis of correlation coefficient.

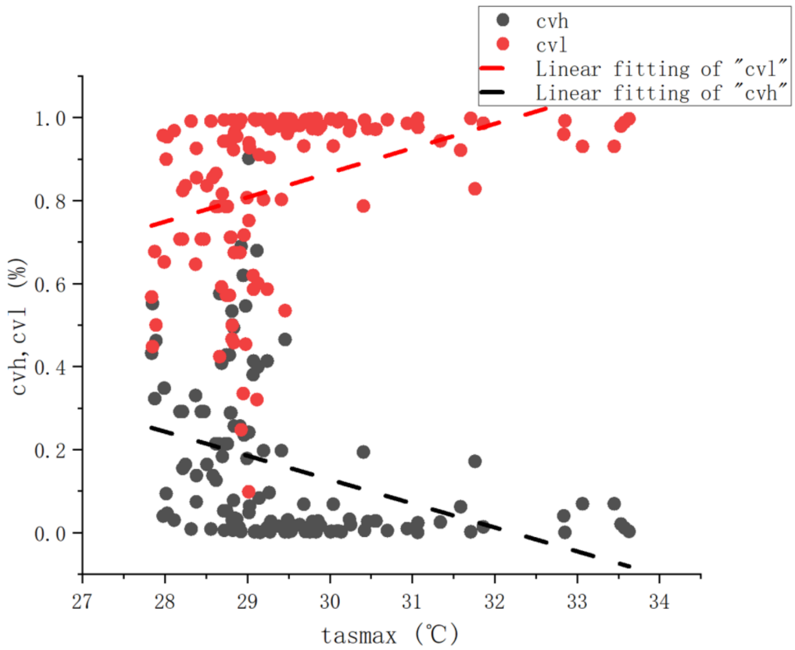

Fig. 5 Scatter analysis and correlations of “cvh” “cvl” tasmax (2022) in inland cities

Table 7. Descriptive statistics of cvh, cvl and tasmax

Variable	Counts	Mean	SD	Sum	Min	Max
tasmax	119	29.48562	1.30023	3508.78899	27.83838	33.62886
cvh	119	0.1575	0.19308	18.74253	4.27266E-4	0.90158
cvl	119	0.83672	0.19704	99.56921	0.09842	0.99808

Table 8. Pearson correlations of cvh, cvl and tasmax

		tasmax	cvh	cvl
tasmax	Pearson Corr.	1	-0.38839*	0.38931*
	p-value	--	1.27289E-5	1.20863E-5
cvh	Pearson Corr.	-0.38839*	1	-0.99779*
	p-value	1.27289E-5	--	1.25888E-139
cvl	Pearson Corr.	0.38931*	-0.99779*	1
	p-value	1.20863E-5	1.25888E-139	--

2-tailed test of significance is used
*: Correlation is significant at the 0.05 level

It can be seen that the conclusions of inland cities are still consistent with the conclusions of the previous overall analysis, and the p-value of tasmax and cvh in Table 8 is lower than the one in Table 4, indicating that it is more necessary to increase the high vegetation coverage for inland cities.

4.2. Costal Cities

The water vapor of coastal cities is more abundant than that of inland cities, and their vegetation growth conditions will be better than those of inland cities in some areas. The difference of vegetation between inland cities and coastal cities results in different regional climate responses [20].

Fig.6 is the scatter analysis of tasmax and vegetation coverage of coastal cities represented by Guangzhou and Shanghai. Table 9 is the data description of the sample points selected for scatter analysis and Table 10 is the analysis of correlation coefficient.

It can be seen that, the conclusions of coastal cities are different from those of the previous overall analysis. The correlation between 'cvh' and 'tasmax' has become a positive correlation, with a p-value greater than 0.01 but less than 0.05. This indicates that the high vegetation coverage of coastal cities is more vulnerable to the reaction of extreme high temperature, and its regulation of extreme temperature is very weak.

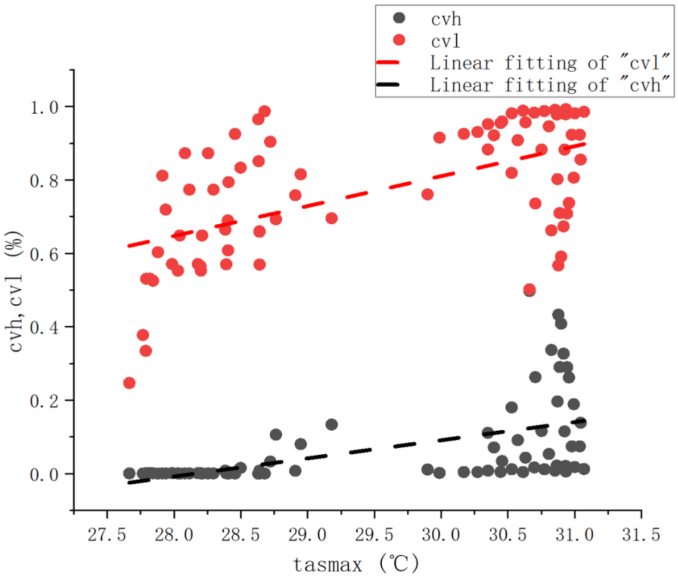

Fig. 6 Scatter analysis and correlations of cvh, cvl and tasmax (2022) in coastal cities

Table 9. Descriptive statistics of cvh, cvl and tasmax

Variable	Counts	Mean	SD	Sum	Min	Max
tasmax	77	29.51576	1.25579	2272.71329	27.6656	31.06915
cvh	77	0.06713	0.1156	5.16913	2.11743E-5	0.49742
cvl	77	0.771	0.17796	59.36668	0.24685	0.99275

Table 10. Pearson correlations of cvh, cvl and tasmax

		tasmax	cvh	cvl
tasmax	Pearson Corr.	1	0.53765*	0.57474*
	p-value	--	4.60414E-7	4.59901E-8
cvh	Pearson Corr.	0.53765*	1	-0.16586*
	p-value	4.60414E-7	--	0.1494
cvl	Pearson Corr.	0.57474*	-0.16586	1
	p-value	4.59901E-8	0.1494	--

2-tailed test of significance is used

*: Correlation is significant at the 0.05 level

In order to make high vegetation to play a role in mitigating the temperature, rather than passively being affected by the reaction of extreme high temperature, it’s necessary to strengthen the protection of high vegetation. Low vegetation coverage needs to be maintained at a moderate value range, which is conducive to the mitigation of extreme temperature.

5. Conclusion

To sum up, vegetation can indeed alleviate the temperature, but its effect on alleviating the temperature varies with the vegetation type and the geographical location of the city. In general, areas with high vegetation types are less likely to have extreme high temperatures. Therefore, it is suggested that the urban area should increase the protection of high vegetation and advocate people to plant high vegetation. The high vegetation in coastal cities is more vulnerable to the reaction of extreme high temperature, and more attention should be paid to the protection of high vegetation. The innovation of this paper is that it breaks the common view that all types of vegetation can regulate climate. It is emphasized that in inland cities, too much low vegetation may cause an increase in extreme temperature, while in coastal cities, an appropriate increase in low vegetation will be conducive to the alleviation of extreme temperature. The existence of low vegetation is conducive to reducing the heating rate, but too much low vegetation may not be conducive to alleviating extreme temperature. Therefore, the low vegetation coverage needs to be kept within an appropriate range, and the specific value of this range needs to be obtained through more experiments and simulations in the future. Moreover, if specific low vegetation values can be obtained later, it will have a good reference value for using vegetation as a factor to limit extreme temperature damage in the future. In addition, if the government can adjust the greening type on this basis and find the most appropriate low vegetation coverage in future research, it will help people reduce the harm of extreme high temperature. Indeed, extreme temperatures are caused by many factors. To restrict its development, many factors need to be adjusted to achieve better results. Future research should explore the causal relationship between different factors and extreme temperatures in order to find more effective ways to alleviate extreme temperatures. At the same time, there are few predictions of future vegetation changes at home and abroad, and the factors used for prediction are also limited. Therefore, the prediction ability of vegetation change should be improved, and a variety of meteorological factors should be used to predict future changes.

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